research review

OAR: The Research Agency
of The United States Air Force

VOLUME IV NUMBER 10 DECEMBER 1965

LASERS AND THE HALL EFFECT

1ST LT THOMAS F. JERRICK, Optical Physics Laboratory, AFCRL

Lasers have been painfully slow in crossing the threshold from promise to application. One reason for the disappointingly slow progress is that satisfactory methods for the broad-band modulation and amplification of laser output have not been uncovered.

An AFCRL contractor, RCA, has recently reported on an experiment that could result in a new technique for modulating and amplifying laser signals. It concerns the observation--for the first time-- of the Hall effect at optical frequencies. More specifically, infrared radiation from a gallium-arsenide wafer was generated by the Hall interaction between a dc magnetic field and the radiation from an He-Ne laser.

Observations of the Hall effect are a standard procedure for analyzing concentrations of charged carriers in conductors and semiconductors, and for studying the nature of the conductivity process in various materials. The normal Hall effect concerns the force that affects charged particles moving in a magnetic field. For example, if electrons are moving perpendicular to a magnetic field, they experience a force perpendicular to both their velocity and the magnetic field. This force can be thought of as the effect of an "induced" electric field in that direction.

The observation of the Hall effect at optical frequencies resulted from the following chain of reasoning: since electromagnetic radiation consists of oscillating electric and magnetic fields, it should be possible to use these fields to produce the Hall effect. Suppose we effectively place stationary electrons in a constant magnetic field. Now we subject them to a coherent electromagnetic field so polarized that its electric vector is perpendicular to the magnetic field. The varying electric field will cause the electrons to move back and forth perpendicular to the magnetic field. This in turn gives rise to the Lorentz force, which will cause the electrons to oscillate at right angles to both the magnetic field and the electric vector--that is, in the direction of propagation of the radiation. This oscillatory motion causes the electrons to radiate coherently in the original direction of propagation.

One can use the antenna theory to predict the characteristics of this radiation. The radiation should occur in a series of lobes at very small angles to the direction of propagation, with the radiation nonpolarized.

These effects were indeed observed in the RCA experiments. Linearly polarized, coherent radiation at 3.39 microns from an He-Ne laser was allowed to fall on a thin

wafer (3.2 x 3.2 x .23 mm.) of GaAs at room temperature. The light transmitted through the wafer was detected by a photodiode. When a pulsed dc magnetic field, aligned perpendicular to the direction of polarization of the light, was switched on, the light transmission increased. Moreover, the increase was not uniform across the face of the wafer, but was in the form of peaks and nulls at small angles to the direction of propagation. The first peak was observed at angles as small as 0.06 degrees. The radiation was also found to be nonpolarized. When the magnetic field was aligned parallel to the incident electric vector, the effect disappeared, as predicted by the theory.

The optical Hall effect could equally well arise from the interaction of a dc electric field and the oscillating magnetic vector of the laser radiation. Work is presently going on to observe this phenomenon. This experiment is especially interesting because of the possibility of transferring energy from the dc electric field to the light frequency field, something not possible with a dc magnetic field. This would in turn lead to the possibility of using the Hall effect for broad-band modulation and amplification at visible and infrared frequencies. ★

Long-Range Electromagnetic Forces on Neutral Systems

DR. ERICH WEIGOLD
Directorate of Physical Sciences, AFOSR

It has been one of the great traditions of science to study the forces acting between various parts of the material world. For instance, Sir Isaac Newton's studies of gravity and celestial mechanics led to his discovery of the law of universal gravitation according to which the force between two massive bodies falls off as the inverse square of the distance r between the bodies. Such forces, which fall off at large distances as an inverse power of the distance between the bodies, rather than exponentially, are known as long-range forces. In quantum

research review
OFFICE OF AEROSPACE RESEARCH

OAR RESEARCH REVIEW is published monthly by the Office of Scientific and Technical Information (RRYC), Hq Office of Aerospace Research, USAF, 4th and Independence Avenue, S.W., Washington, D.C. 20333. The objective of this publication is to make a positive contribution to the exchange of information concerning Air Force conducted and sponsored research activities.

JACOB SEIDEN
Editor

LASERS AND THE HALL EFFECT
1st Lt. Thomas F. Jerrick 1

LONG-RANGE ELECTROMAGNETIC FORCES ON NEUTRAL SYSTEMS
Dr. Erich Weigold 2

SEMICONDUCTOR SURFACE STUDIES BY LOW-ENERGY ELECTRON DIFFRACTION
Max Swerdlow 4

SADSAC (Seiler Algol Digitally Simulated Analog Computer)
Capt. James E. Funk 11

INTERNATIONAL SYMPOSIUM ON MULTIVARIATE ANALYSIS
Dr. P. R. Krishnaiah 12

PLASMA CHEMISTRY
Col. Milton D. Sprinkel 13

THE ELASTIC BEHAVIOR OF CHROMIUM DEPENDS ON HOW YOU TEST IT—OR POISSON'S RATIO—THE VARIABLE CONSTANT
J. A. Roberson and Dr. H. A. Lipsitt 16

MOLECULAR MARKSMANSHIP (Molecular-Beam Research)
Optical Physics Laboratory, AFCRL 19

DYNAMIC REFLECTANCE SPECTROSCOPY
Denton W. Elliott 20

SOME NUCLEAR-STRUCTURE STUDIES USING GAMMA-RAY ANGULAR CORRELATIONS
Dr. D. D. Watson 24

LABILE SPECIES OF CARBON
Dr. Anthony J. Matuszko 26

ORGANIZATIONAL BEHAVIOR IN A DISASTER STRESS SITUATION
Dr. H. J. Sander 28

CURIOUS CLOUD STRUCTURE
Meteorology Laboratory, AFCRL 29

For sale by the Superintendent of Documents, U.S. Government Printing Office Washington, D.C. 20402 - $2.75 per year domestic, 75 cents additional for foreign mailing, 25 cents per single copy and 15 cents per Annual Index. Back issues will not be furnished.

theory, long-range forces may result from the exchange of massless quanta between the interacting systems. The most familiar example in quantum mechanics is the inverse square Coulomb force between charged particles arising from the exchange of a single photon between the particles.

Until recently, very little was known about the forces between two neutral systems for which the gravitational attraction is too weak to be of direct interest. Such forces exist between neutral molecules, and they determine many of the characteristics of familiar substances. These intermolecular forces are known as van dér Waals forces, and they determine, among other things, the surface tension and viscosity of liquids and their solubility in other liquids.

The first quantitative theory of van der Waals forces was advanced by the German physicist, Fritz London, in 1930.(1) According to this theory, the intermolecular forces arise from second-order perturbation theory applied to the electrostatic interaction between two dipoles. The energy of the interaction turns out to be proportional to r^{-6} and the force to r^{-7}. London's approach is certainly not valid at large separations when r is of the order of the wave length of the exchanged photons corresponding to transitions between the ground state and the excited states of the system. At these large separations there will be considerable phase shifts in the exchanged radiation which must be considered in computing the force. The influence of these retardation effects in the interaction between atoms was first considered by the Dutch physicists, H.G. B. Casimir and D. Polder(2), who worked out an electromagnetic theory of the intermolecular force in 1948. Casimir and Polder found that, at relatively large distances, the interaction energy and the force are proportional to r^{-7} and r^{-8}, respectively, in contradiction to the London expressions.

In a paper submitted to the Physical Review, Professors J. Sucher of the University of Maryland and G. Feinberg of Columbia University described their much more general quantum field theory calculations of the forces acting between pairs of particles, at least one of which is neutral and spinless (i.e., it has no angular momentum). This work, supported in part by an AFOSR grant, was prompted by a desire to establish whether or not such long-range forces are presently observable in particle physics. One of the interesting results of the work was the proof that the result of Casimir and Polder concerning van der Waals forces is quite general, being independent of the detailed dynamical models for the individual interacting systems. Of particular interest to Feinberg and Sucher was the result that the long-range force between the K mesons can induce transitions between the K_1^0 and K_2^0 particle states. Unfortunately, the regeneration rate of K_1's from K_2's proved to be too small to allow an experimental determination of the long-range force.

There is, however, one difference between the case of two atoms and the case of two elementary particles due to their different binding energies. Atoms, bound by electromagnetic interactions, have excited states separated by energies of the order of $\alpha^2 m_e$ from the ground state ($\alpha = 1/137$ is the fine structure constant and $m_e = 0.51$ Mev is the electron mass). On the other hand, the excited states of particles are separated by the order of the pion mass. As a consequence of this, the interaction potentials contain exponential terms of the form $\exp\left[-\frac{\alpha r}{a_0}\right]$ and $\exp\left[-\frac{r}{\lambda_\pi}\right]$ for the atomic and particle cases respectively, where a_0 is of the order of the Bohr radius, and λ_π the pion Compton wave length. Therefore, for the atomic and molecular case, the exponential rather than the r^{-7} terms may dominate the interaction potential for many atomic radii.

In summary, one may say that, since the nature of forces between atoms determines the properties of macroscopic matter, the improved understanding of these forces gained from the work of Feinberg and Sucher is clearly of importance in connection with attempts to comprehend and/or predict such properties. ★

(1) London, F., Zeitschrift fur Phys., 60, 491, 1930.
(2) Casimir, H. G. B. and D. Polder, Phys Rev., 73, 360, 1948.

semiconductor surface studies by low-energy electron diffraction

MAX SWERDLOW, Directorate of Physical Sciences, AFOSR

Recent years have witnessed a great revival of interest, in the scientific and technological fields, concerning the surfaces of solid materials.* The most important reason for this revival is the realization that solid surfaces play a very important, sometimes overwhelming, role in many physical phenomena of vital interest to mankind. These phenomena range from catalysis to corrosion (or resistance to corrosion), from friction (and methods to avoid it) to electronic behavior and crystal growth. For example, catalysis, i.e., the process related to a chemical reaction proceeding on the surface of a solid, has remained for many years an art, rather than a science, because of insufficient understanding of the nature of solid surfaces. Yet, the discovery of a new catalyst can, and did, stimulate the establishment of entirely new industries. Thus, the production of synthetic nitrogenous fertilizer stemmed from the discovery (in 1913) of an iron catalyst that permitted nitrogen and hydrogen to be combined economically into ammonia gas. In 1962, more than 12 million tons of nitrogen from the atmosphere were combined by this process throughout the world. (1) The development of the "fuel cell," presently considered indispensable for interplanetary travel, is based upon the discovery that the reaction between hydrogen and oxygen to form water proceeds more efficiently and in a more controllable fashion on the surface of platinum wires. A better understanding of the chemical reactivity of solid surfaces is bound to stimulate new discoveries and progress in catalysis. Surface reactivity, in turn, should be related to the arrangement of atoms at or near the surface.

The electronic behavior of solids, to pick another example, is often inextricably related to the nature of the surface as well. Electrons are emitted through the surfaces of cathodes in electron tubes; photoelectric phenomena are highly dependent on the structure of the surface. While the need for miniaturization requires smaller and smaller electronic components, the ratio of surface to volume for such devices becomes larger and larger. Hence, even the adsorption of gases on the surface can affect the characteristics of devices because such adsorption can influence electron transport, surface diffusion, and other phenomena. In this respect, the surface plays a predominant role in the malfunctioning of devices. But there are also solid-state components, such as the field-effect and the point-contact transistor, whose functioning is indeed based upon surface phenomena that are little or not at all understood. The properties of thin-film resistors and capacitors are strongly affected by surface characteristics and, above all, the very preparation of thin films of crystalline materials is intimately connected to the nature of the surface. In fact, if one thinks of every atom inside a crystal as having once been on the surface during the growth process, one will see a relationship between crystal growth or erosion and surface phenomena such as nucleation, atomic mobility and diffusion, thermal characteristics and so on.

Advances in the "engineering" studies of surfaces have been developed in the past mainly from empirical approaches. The results have been, therefore, mainly qualitative. It has generally been assumed, rather naively, that the atoms located on a given surface have the same arrangement as the atoms in a parallel plane inside the crystal. This simple view is occasionally correct, and often quite adequate, but is sometimes very wrong. This is because the immediate neighborhood of an atom is quite different depending on whether it is located in the bulk

*For additional information on "Surface Studies and the Mössbauer Effect," the reader is referred to the Nov. 1965 issue of the OAR Research Review.

or on the surface of a crystal. In the former case, the atom is surrounded by other atoms on all sides, while on the surface the atom has neighbors only on one side. Hence, the forces acting on a surface atom are not symmetrical and, as such, are likely to affect the atom's behavior and location on the surface. It is reasonable, therefore, to think that better and quantitative understanding of surface phenomena will be favored by knowledge of the structure of the surface, namely, the distribution and arrangement of atoms and of the chemical bonds that hold them together.

A great impetus in this direction resulted from the development of highly sophisticated experimental techniques. One of these, the ultrahigh vacuum technique, is absolutely essential for the preparation and maintenance of "clean" surfaces. Why do we want clean surfaces and why do we need an ultrahigh vacuum to study them? It is a known fact that all surfaces, under normal atmospheric conditions, are covered with very thin layers of adsorbed gases, oxides, and impurities. When a surface is exposed to air, each atom on the surface is struck about a billion times a second by air molecules, and most of these molecules are likely to stick to the surface. Obviously, if we want to study such intrinsic phenomena at the surface as gas adsorption and oxidation, we must be able to eliminate all, or almost all, foreign atoms, i.e., achieve the "atomically clean" state. We must, therefore, develop methods for cleaning the surface and for keeping it clean long enough for the experiments that we have in mind. If we could, in fact, achieve the atomically clean state on a surface at room temperature and atmospheric pressure, we would find the surface covered with a monolayer of adsorbed gases after only one nanosecond. Even at the low pressures that are easily achievable in ordinary vacuum systems (10^{-5} - 10^{-6} torr*), it would take only about a second for a clean surface to be completely covered by a layer of adsorbed gas. These time lapses are obviously too short to allow reliable studies of surface effects. Hence, the pressure must be lowered further and made to approach the level found in interplanetary space. Actually, very satisfactory surface studies are carried out in the range of 10^{-9} -10^{-10} torr.

Torr is the unit commonly used for measuring low pressures. It is a little more than one thousandth of standard atmospheric pressure.

To know the methods for cleaning surfaces and to know their environment are obviously necessary, but not by themselves sufficient. For quantitative studies, we need, also, techniques for recognizing and monitoring the state of the surface during an experiment. One such technique resulted from the application of the phenomenon of field emission and ionization, by Mueller, (2) to the observation of atomic arrangements on the surface of a crystal tip. This technique (called field-emission and field-ion microscopy) stimulated significant efforts by Mueller himself, (3) Gomer, (4) Brandon, (5) and others toward the understanding of the detailed mechanism of the important phenomenon of field desorption. Another equally powerful and complementary technique is that of electron diffraction, particularly that part of it that makes use of electrons with energies lower than, say, 500 volts, which is known as low-energy electron diffraction (LEED). The discovery that electrons can produce diffraction patterns when they are led to interact with a crystalline lattice was made in 1927 by Davisson and Germer. Low-energy electrons are very suitable for the study of surfaces because their penetration into the bulk of the solid is very slight. They rapidly lose energy on collisions with the atoms in the lattice. Only those that are scattered, mostly in the backward direction, by the crystal atoms without loss of energy (elastic scattering) contribute to the diffraction pattern. This diffraction pattern, therefore, gives direct information about the nature and the structure of the solid surface because the electrons that form this pattern have interacted only with the very few uppermost atomic layers in the solid. If these layers are noncrystalline, such as glassy oxides, the information is rather sparse, as the scattered electronic radiation is diffused over a large area with no immediately recognizable pattern. If, on the other hand, the

surface layer is crystalline, a characteristic pattern is observable; the more perfect the order of the atomic arrangement within the surface layer, the better defined this pattern is. Hence, it is clear that a "dirty" surface will not yield a LEED pattern; in fact, it will yield no pattern at all, if by "dirty" we mean the condition of a surface completely covered with an amorphous layer of chemisorbed material. A perfectly clean, crystalline surface, on the other hand, will always yield a very well-defined LEED pattern. The converse, however, is not necessarily true. The observation of a sharply defined pattern is not necessarily proof that the surface producing it is perfectly clean, i.e., free of all impurities. It must be recognized that achievement of the atomically clean state is a three-dimensional problem. It is, in fact, quite unlikely that the presence of a small percentage of impurities on the surface can be avoided with the techniques employed at present. These impurities may originate in the bulk and diffuse onto the surface during the heat treatments often used in the course of the cleaning process. They may also originate in the surroundings of the surface studied (walls of the vacuum system, residual

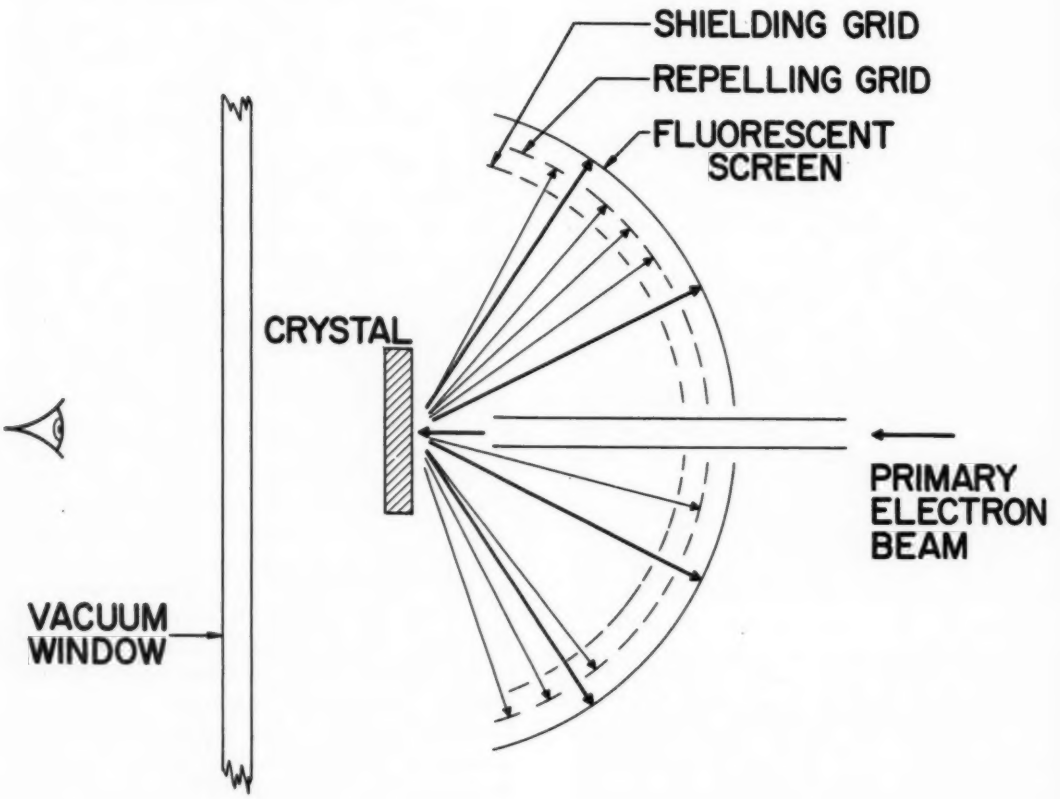


Figure 1 Schematic drawing of the LEED optics. The purpose of the shielding grid is to provide a field-free space for the electrons. A small negative voltage between the shielding grid and the repelling grid rejects all electrons that have undergone inelastic scattering (thin arrows). The elastically scattered electrons (heavy arrows) are allowed to enter the gap between the repelling grid and fluorescent screen, where a strong electric field accelerates them toward the screen.

gases, etc.), and react with the surface at high temperatures.

Although the LEED technique, actually 38 years old, was skillfully used for several years by Farnsworth and co-workers, (6) it was not until 1960 that Germer and co-workers (7, 8) achieved a very important modification that allows the display of the diffraction pattern on a screen for continuous inspection. This modification utilizes the "post-diffraction acceleration" principle that was invented by Ehrenberg in 1934. Figure 1 depicts schematically the principle involved. The low-energy electrons impinge on the crystal surface under study from a suitable electron gun through a collimating tube. The crystal sample is located at the center of a hemispherical arrangement of two very-fine-mesh grids and a fluorescent screen. The first, or shielding, grid is generally maintained at the same potential as the crystal (ground), so as to provide a field-free space in which the electrons can move unimpeded. The electrons that have been scattered inelastically from the solid surface are eliminated from the picture by having them rejected by a small negative field applied between the shielding grid and the second grid, called the repelling grid. The electrons that have been scattered elastically are energetic enough to cross the repelling grid. They are then accelerated by a strong positive field onto the fluorescent screen where they excite the screen material to the point of causing emission of visible light. The observer located just outside the LEED chamber can then see, through a window, a pattern of spots which recalls a Laue X-ray diffraction pattern. The position of the spots on the screen, having been determined by the diffraction angle, give information about the geometry, the periodicity and the basic symmetry of the surface structure. The intensities of the spots contain information about the actual distribution of the atoms in the three or four uppermost layers of the solid.

Scientists have investigated the surfaces of a number of metals, semiconductors, and two-element compounds with display-type LEED equipment. The interest in semiconductor surfaces is both technological and fundamental in nature. In fact, it was found by Lander and co-workers (9) that, although clean metal surfaces exhibit atomic arrangements identical to those known from X-ray work to exist on planes parallel to the surface within the bulk, clean surfaces of semiconductors such as Si or Ge often exhibit "reconstructed" atomic arrangements. The atoms rearrange themselves within the surface layer, no doubt because of the strong directional nature of the bonding that characterizes the diamond-type semiconductors. The result is the formation of a superlattice, or supernet, on the surface, which arises from increased periodicity in one or two of the crystallographic planes that lie on the surface. This phenomenon of atomic rearrangement on the surface is generally called "reconstruction" of the surface. A re-examination of the cleaning procedures (10) and of the various types of supernets that can be observed on clean surfaces of Si, Ge and GaAs (11) has been carried out by Dr. F. Jona at the IBM Watson Research Center under AFOSR sponsorship. Most of the surface structures that were previously reported by the Bell Telephone workers could be reproduced, and some could not. In addition, a number of new surface structures were observed.

It may be useful to recall here the structural characteristics of the semiconductors investigated. Figure 2(a) depicts the unit cell of the bulk structure of Si or Ge, the atoms being indicated with circles and the bonds that hold them together with arrow-like lines (to give some perspective). Any plane through this unit cell can, in principle, become the surface if the crystal is cut accordingly. We have singled out, in Figs. 2(b), 2(c) and 2(d), the three planes called the [100] face, [110] face, and [111] face, respectively, that have been the object of LEED studies. The figures indicate the distributions of atoms on these planes as they are known from X-ray studies. It must be realized, of course, that such atomic planes are useful geometrical concepts, but do not adequately represent the corresponding "surfaces" of the crystal. This is so because a real surface does not involve

one single atomic plane only, say, the top layer of atoms, but involves also the second and third layer at least. Certainly, at least that many atomic layers contribute to the LEED patterns that are observed. This fact plays an important role in the interpretation of LEED patterns, as may be understood by means of one example: the [100] face of gallium arsenide, GaAs. This semiconductor has a bulk structure similar to that of Si and Ge, but contains, of course, two different atoms, Ga and As; the resulting unit cell is depicted in Fig. 3(a) where the white circles represent Ga atoms, and the gray balls denote As atoms. Now, if we want to prepare a [100] face we may cut the crystal so as to have only Ga atoms on the top layer, Fig. 3(b), or only As atoms, Fig. 3(c). As far as atomic distribution on the top layer is concerned, the Ga face of Fig. 3(b), the As face of Fig. 3(c), and the Si or Ge face of Fig. 2(b) are identical. If, however, we take the second

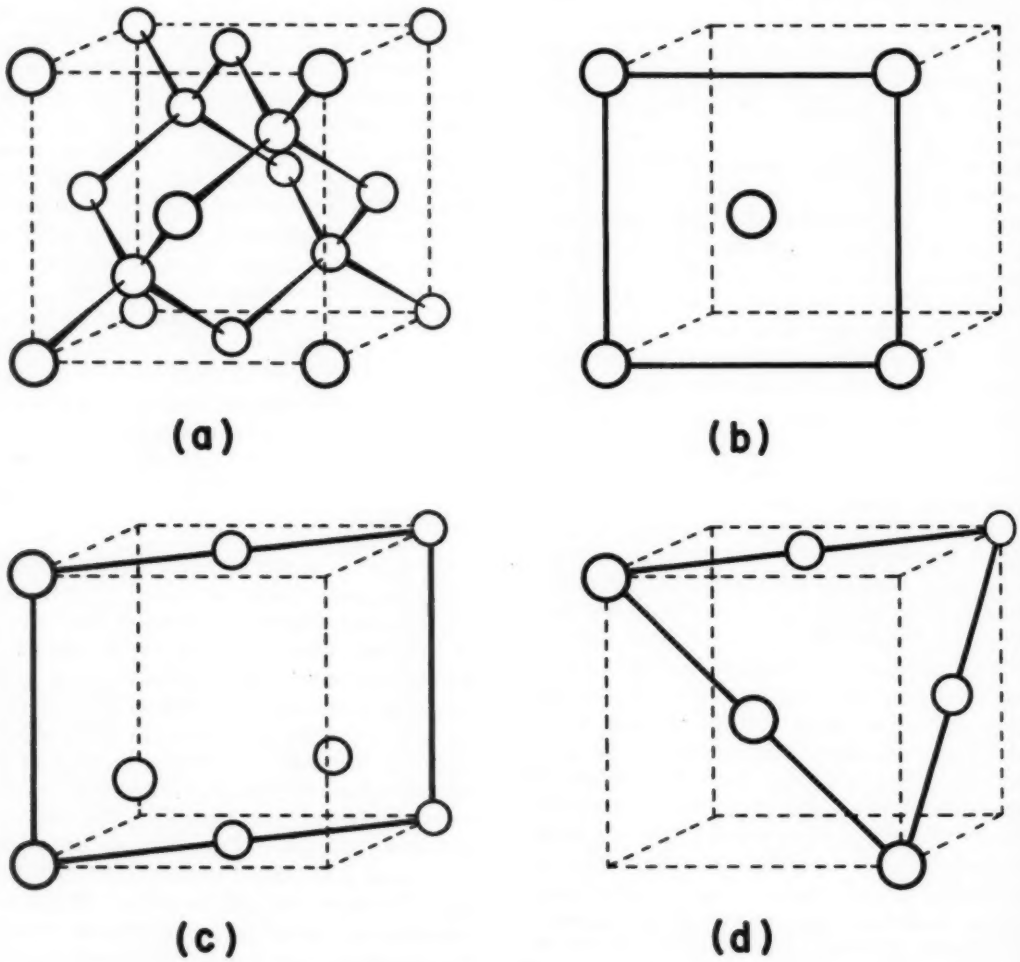


Figure 2 The crystal structure of silicon and germanium. (a) Unit cell with bonds between atoms indicated perspectively. (b) Ideal distribution of atoms on a cube face, called the [100] face. (c) Ideal distribution of atoms on a diagonal face, called the [110] face. (d) Ideal distribution of atoms on another type of diagonal face, called the [111] face.

layer into account, we find that there is already a difference between the two [100] "surfaces" of GaAs sketched in Figs. 3(b) and (c). In 3(b), the second layer below the Ga face consists of As atoms aligned along one of the face diagonals. In Fig. 3(c), the second layer below the As face consists of Ga atoms aligned along the other face diagonal. Thus, on the basis of these arguments alone we must expect different diffraction patterns from a Ga face or an As face of the [100] surface of GaAs. There are, in other words, two different types of [100] surfaces on crystals such as GaAs. The difference in LEED patterns is apparent from the photographs shown in Fig. 4(b) and (c) when com-

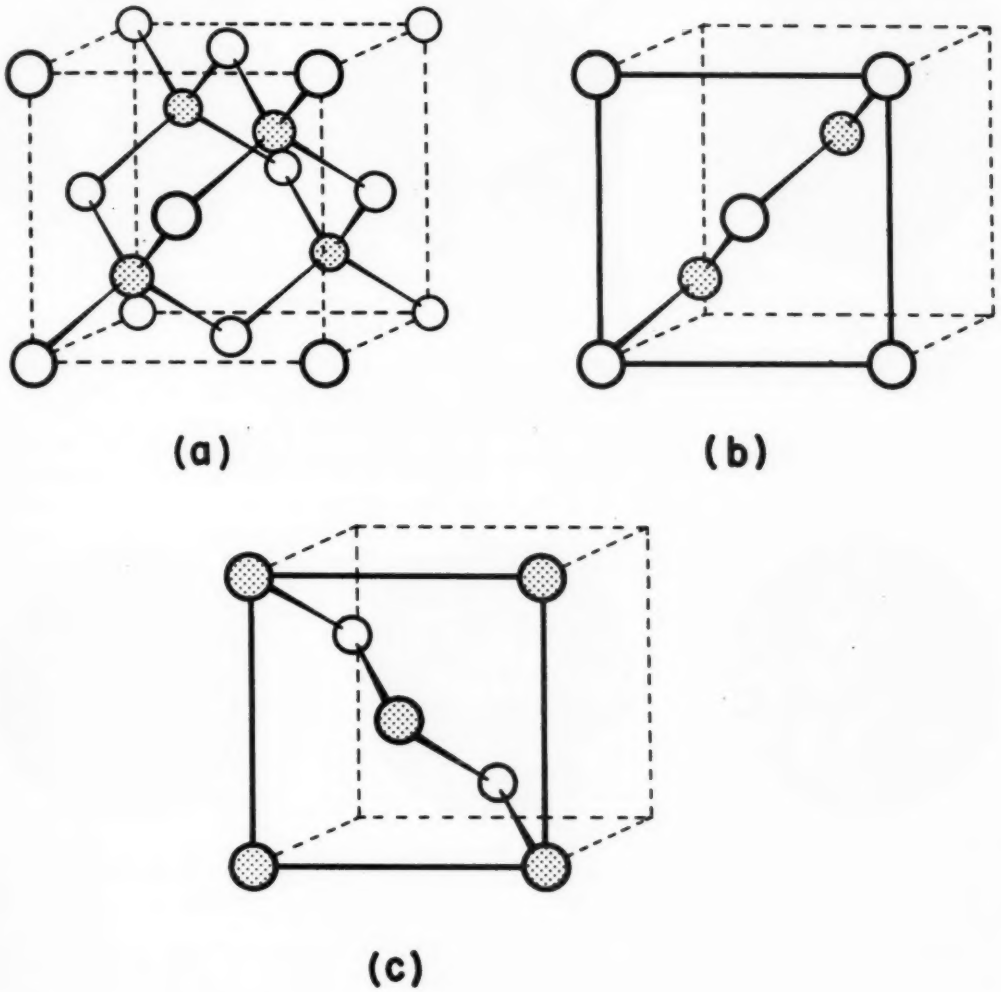


Figure 3 The crystal structure of GaAs

(a) Unit cell: the white circles represent Ga, the gray circles denote As atoms.

(b) Ideal distribution of Ga atoms on the first layer and As atoms on the second layer of a cube face.

(c) Ideal distribution of As atoms on the first layer and Ga atoms on the second layer of a cube face.

pared with the pattern obtained from a cube face of Si as depicted in Fig. 4(a). Part of the difference observed is, of course, to be ascribed to the "reconstruction" of the surface structures as discussed previously.

Surface reconstruction is mainly responsible for the differences in structures observed on the [111] surfaces (also called "octahedral" faces because they have the same orientation as the faces of an octahedron), and on the [110] surfaces of Si, Ge, and GaAs. Typical LEED patterns are shown in Fig. 5 for [111] surfaces and in Fig. 6 for [110] surfaces. It should be noted, in

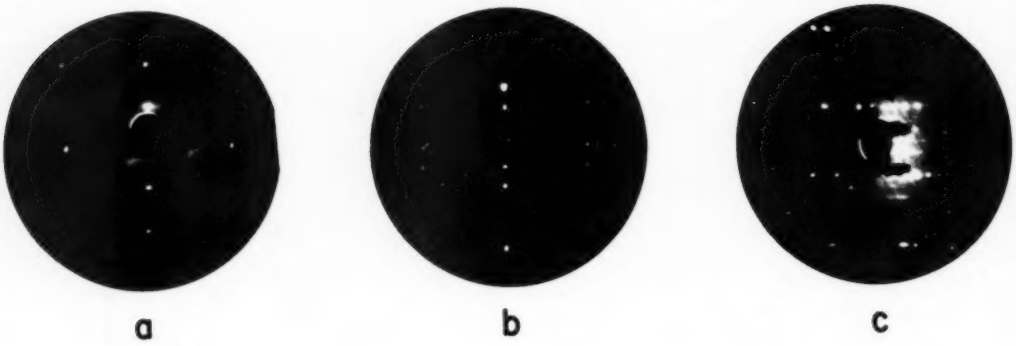


Figure 4 LEED patterns of [100] surfaces
(a) Si surface (electron energy 68 e V)
(b) GaAs surface, Ga - face (electron energy 49 e V)
(c) GaAs surface, As - face (electron energy 62 e V)

Figure 5 LEED patterns of [111] surfaces
(a) Si (electron energy 36 e V)
(b) Ge (electron energy 58 e V)
(c) GaAs (electron energy 31 e V)

connection with the latter surfaces, that silicon behaves peculiarly, for a number of different structures can be observed on the same surface after different heat treatments. Only two of them are shown in Fig. 6(b) and (c). The detailed natures of these structures are not understood, at present, nor is it known whether they are due to minute amounts of extraneous impurities or are indeed different phases of the same clean surface. The answer to this question may be important for explaining, for example, the effect of sub-

Figure 6 LEED patterns of [110] surfaces
(a) GaAs (electron energy 125 e V)
(b) Si (electron energy 58 e V)
(c) Si (electron energy 51 e V)
[(b) and (c) represent two different structures of the same surface that can be obtained after different heat treatments.]

strate temperature on the quality of epitaxial layers grown from the vapor phase.

In conclusion, it may be stated that, with the LEED technique, a great deal has been learned already about surfaces of crystalline solids in general, and semiconductors in particular. It is true that LEED has actually raised more questions, so far, than it has answered; but it has also uncovered more new facts about solid surfaces than any other technique. There is no doubt but that it will play a vital role, in the near future, in the process of understanding the complicated physical and chemical nature of interfaces.

References

1. *Germain, J. E., Internat. Science and Technology, No. 45, September 1965.*
2. *Mueller, E. W., Ergebn. exakt. Naturwiss., 27, 290, 1953.*
3. *Mueller, E. W., Surface Science, 2, 484, 1964.*
4. *Gomer, R., Field Emission and Field Ionization, Harvard Univ. Press, 1961.*
5. *Brandon, D. G., Surface Science 2, 495, 1964.*
6. *See, for ex., Schlier, R. E. and H. E. Farnsworth, in Semiconductor Surface Physics, University of Pennsylvania Press, 1957, P. 3.*
7. *Scheibner, E. J., L. H. Germer, and C. D. Hartman, Rev. Sci. Instr., 31, 112, 1960.*
8. *Germer, L. H. and C. D. Hartman, Rev. Sci. Instr., 31, 784, 1960.*
9. *See, for ex., Lander, J. J., Recent Progress in Solid State Chemistry, (Editor, H. Reiss).*
10. *Jona, F., Applied Physics Letters, 6, No. 10, 205, 1965.*
11. *Jona, F., IBM Journ. Res. and Develop., Sep-Nov 1965.*

SADSAC
(Seiler Algol Digitally Simulated Analog Computer)

CAPT JAMES E. FUNK
Aerospace Mechanics Division, FJSRL

The most time-consuming and tedious task in the use of a digital computer is the programming, or instructing the digital computer on how to solve a problem. However, for an analog computer, the programming is quite simple. Thus, a desirable procedure would be to program a problem as an analog simulation, and solve it digitally. Such a procedure, called SLASH (1), has recently been published by Captain James E. Funk of the Aerospace Mechanics Division, Frank J. Seiler Research Laboratory.

SLASH (for Seiler Laboratory Algol Simulated Hybrid) was written specifically for the Burroughs B-5500 digital computer. It

was patterned after the MIDAS FORTRAN analog simulation. SLASH is well suited to most systems of ordinary differential equations. The analog portion of the program, SADSAC (Seiler Algol Digitally Simulated Analog Computer) permits programming directly from an operational block diagram--a simple method of setting up a problem. The inputs of each element on the block diagram are listed on a special coding form from which cards can be key punched directly. The key-punched cards, along with a few "control cards," are submitted as "data" to the SLASH program. SADSAC acts as an "interpreter" setting up the program to perform the necessary digital computations from the information given on the coded data cards.

The hybrid features of the program allow arithmetical, algebraic, and logical operations to be coded digitally in Algol, or to be performed by the precoded analog elements of SADSAC. The advantage of the analog elements is primarily the ease of programming, while the main advantages of digital coding can be either in time saving and/or as a reduction of analog elements for complicated mathematical functions. Also, the digital program is well suited to the time-invariant calculations that are characteristic of many aerospace problems of Air Force interest. SLASH also includes a plot routine which automatically graphs the results, thereby aiding greatly the analysis of numerical data.

SLASH is a very flexible program, and is presently being used in the Seiler Laboratory to solve problems in control theory. It has been used in the past by USAF Academy cadets doing research projects, and is scheduled for use as an optional tool in future cadet courses. The University of Virginia, Chemical Engineering Department, is presently using the SLASH program for some of its graduate studies. ★

Reference

(1) Funk, Capt James E., "SLASH, Algol Simulated Hybrid Computer," SRL 65-1, Frank J. Seiler Research Laboratory, USAF Academy, Colo., 1965.

international symposium on multivariate analysis

DR. P. R. KRISHNAIAH, Applied Mathematics Research Laboratory, ARL

In any experiment, measurements are made on one or several variables. The experiment is said to be univariate or multivariate depending on whether the measurements are made on one or several variables. For example, if one measures the heights of a group of individuals, it is called a univariate experiment. On the other hand, if one measures their heights, weights, lengths of arms, chest sizes, etc., it is called a multivariate experiment. Statistical analysis made on the basis of several variables is called Multivariate Analysis. Multivariate Analysis itself is an important branch of statistics.

In the United States Air Force, the field of Multivariate Analysis plays an important role in drawing conclusions or making predictions about the life expectancy of planes or machines, and in other problems. Applications of Multivariate Analysis can also be cited in the physical, engineering, social, biological and other sciences. The tools of Multivariate Analysis are instrumental in obtaining greater assurance of the validity of results, maximum precision of experimentation, and efficient experimentation with respect to the economy of time, cost, and availability of equipment and personnel.

The First International Symposium on Multivariate Analysis was held 14-19 June 1965 under the sponsorship of the Aerospace Research Laboratories. The symposium took place at the John F. Kennedy Memorial Union building on the University of Dayton campus. More than 260 statisticians from Australia, Canada, England, Germany, India, Japan, Sweden and the United States attended the symposium. Thirty invited papers were presented by prominent statisticians working in different areas of Multivariate Analysis.

The Proceedings of the symposium will be published as a bound volume by Academic Press. ★

PLASMA CHEMISTRY

COL MILTON D. SPRINKEL, Directorate of Chemical Sciences, AFOSR

The chemistry of the hottest stars is being simulated by versatile research devices at the University of California in Los Angeles. These are unique plasma torches with a modified design which have been constructed by Dr. Willard F. Libby and his associates in the AFOSR-UCLA Space Chemistry Program.

These devices use radio-frequency-inductive heating to concentrate a large amount of energy in a gas, which is contained in a volume of about one liter. At the ultrahigh temperatures thus produced, gases passing through the torch become highly ionized and luminescent, characteristics of the plasma state of matter. Experiments establishing the feasibility of using radio-frequency-induction heating for producing high-temperature gas have been carried on previously by Reed at Lincoln Laboratory, and by others. The UCLA plasma torches, because of circuitry innovations, take advantage of the extremely rapid response time between power tube control and plasma response, and the plasma power can be modulated in almost any conceivable manner. For example, plasma pulses of enormous power and intensity can be generated for very short duration (on the order of a million watts for periods of microseconds or less).

Temperatures achieved within these torches range upwards from 2,800 degrees C. Present models have a design capability of about 40,000 degrees C., corresponding to the surface temperatures of the hottest known stars, the blue dwarfs, and roughly 10 times hotter than the surface of the sun. The highest temperatures achieved thus far are probably in the range of 28,000 degrees C. Devices now in the testing phase are believed capable of continuous plasma generation at pressures of the order of one atmosphere, in the range of about 100,000 degrees C.

The torches provide a laboratory source of extremely hot, pure plasma which can be precisely modulated, and whose composition can be varied widely. Thus, they serve as versatile tools for chemical research in astronomy. While most elements present in a star are identifiable through conventional spectroscopic techniques, determination of both their relative and absolute quantities has previously been impossible in most cases. Comparison spectra were necessary from uncontaminated, ultrahigh plasmas of known and variable composition at the temperature of the star studied. The UCLA torches are now providing uncontaminated spectra of gases whose composition may be varied with accuracy. These spectra may now be compared to solar and stellar spectra obtained astronomically. Furthermore, the simulated spectra provide information in the nonvisible range absorbed by the earth's atmosphere.

This versatility is expected to make possible significant advances in many areas of plasma chemistry. In general, plasma researchers have not made full use of torch-type generators because of problems associated with controlling the steady-state torch, and because there are too many processes going on in the plasma for it to be easy to unravel theoretically. In addition it is planned to use these torches to experimentally check the theoretical F values for various elements in the sun.

One of the plasma torches was demonstrated publicly for the first time in the AFOSR exhibit of the Space Chemistry Program at the annual meeting of the American Association for the Advancement of Science at Montreal, 26-30 December 1964. ★

References

(1) *Libby, W. F., Science in the Sixties, The 10th Anniversary AFOSR Seminar, Chapter XIV, Albuquerque, University of New Mexico Press, 1965.*

(2) *Reed, Thomas B., "Plasma Torches," International Science and Technology, 42-47, June 1962.*

ARL scientists excel at recent Air Force Science and Engineering Symposium

Scientists from the Aerospace Research Laboratories (ARL) captured two of the three top awards recently during the 12th Annual Air Force Science and Engineering Symposium held at Brooks AFB, Texas, 12-14 October 1965.

Dr. Wilbur L. Hankey, Jr., and Captain Lawrence J. Schroeder of ARL's Hypersonic Research Laboratory captured the Air Force Association Aerospace Education Foundation Award for the first-place paper. Mr. Karl Scheller, Dr. Ulrich Grimm and Dr. Gerhard W. Mueller of ARL's Chemistry Research Laboratory were awarded the third-place award.

It was the second straight year that ARL scientists have captured the top prize. Last year Dr. Harry A. Lipsitt of ARL's Metallurgy and Ceramics Research Laboratory captured first place.

The paper coauthored by Dr. Hankey and Captain Schroeder, entitled "Optimization of Lifting Re-entry Bodies," concerned lifting configurations optimized to produce maximum hypersonic Lift/Drag (L/D) for constraints of heating, skin friction, stability, and conventional landing requirements.

Dr. Hankey, an aerospace research engineer, is currently conducting theoretical studies in the optimization of hypersonic configurations. He previously worked for the Aeronautical Systems Division and published a handbook for computing aerodynamic characteristics for lifting re-entry vehicles. He received the ASD's Most Distinguished Engineering Paper Award for the book in 1962, and again received the award in 1963 for another paper. Dr. Hankey received his B.S. degree in Aeronautical Engineering in 1951 from Pennsylvania State University. He earned his M.S. degree at the Massachusetts Institute of Technology in 1953, and his Ph.D. at Ohio State University in 1962.

Captain Schroeder joined ARL in March 1964 as a research engineer. He was graduated from Iowa State University in 1956 with a B.S. degree in Aeronautical Engineering and a commission as second lieutenant. After serving as a transport pilot with the Military Air Transport Service (MATS), he received an assignment to the Air Force Institute of Technology in 1962, which permitted him to earn his M.S. degree in Aerospace Engineering at the University of Oklahoma in January 1964.

The paper by Mr. Scheller, Dr. Grimm and Dr. Mueller was entitled "Heat Transfer from Oxygen at High Temperatures." It discussed theoretical and experimental investigation of heat transfer to the end wall of a shock tube behind a reflected shock wave in oxygen under conditions ranging from zero to nearly complete dissociation.

Mr. Scheller, an aerospace research engineer, conducts investigations of kinetic mechanisms in flames and detonations, and energy transport in reacting gases. He received his B.S. degree from the Cooper Union Institute of Technology in New York City in 1939, and his M.S. degree at Ohio State University in 1948, both in Chemical Engineering.

Dr. Grimm, a research chemist, is currently engaged in research on the kinetics of reactions in gaseous shock and detonation waves and energy transport in dissociating gases. From 1953-61, he was a research fellow at the Institute of Physical Chemistry, University of Goettingen, Germany. He earned his M.S. and Ph.D. degrees in Physical Chemistry at the University of Goettingen, and his B.S. in Chemistry at the Technical Institute in Darmstadt, Germany.

Dr. Mueller, a research chemist, joined ARL in March 1965. His current research involves the physical chemistry of combustion and detonation processes, and studies of reaction kinetics and energy transfer in shock waves. He received his B.S. and M.S. degrees in Physical Chemistry at the University of Goettingen, and his Ph.D. at the Hannover Institute of Technology in 1960. ★

Capt Lawrence J. Schroeder (left), ARL research engineer, and Dr. Wilbur L. Hankey (center), ARL aerospace research engineer, both at ARL's Hypersonic Research Laboratory, accept the Air Force Association's (AFA) First-Place Aerospace Education Foundation Award from Mr. Earl N. Parker (right), National Director of AFA. Capt Schroeder and Dr. Hankey were recognized for their outstanding scientific research paper entitled "Optimization of Lifting Re-Entry Bodies," which they coauthored. Their paper was selected by the Chief Scientist, Headquarters United States Air Force. The award consisted of a $300 cash prize and an engraved plaque.

Mr. Karl Scheller (left), aerospace research engineer at ARL's Chemistry Research Laboratory, receives Air Force Association Aerospace Education Foundation Award, Third Place, from Mr. Earl N. Parker (right), National Director of AFA, for paper, "Heat Transfer from Oxygen at High Temperatures."

THE ELASTIC BEHAVIOR OF CHROMIUM DEPENDS ON HOW YOU TEST IT- OR POISSON'S RATIO - THE VARIABLE CONSTANT

J. A. ROBERSON and DR. H. A. LIPSITT
Metallurgy and Ceramics Research Laboratory, ARL

Metallic chromium undergoes a transition from an ordered antiferromagnetic to a disordered paramagnetic spin array as its temperature is increased through the range of 37^{o} to 40^{o} C. This transition is accompanied by abrupt changes in many of the physical properties of the metal. Recent work in the Metallurgy and Ceramics Research Laboratory of ARL has confirmed the findings of previous investigators that there are anomalous changes in Young's modulus and Poisson's ratio in this temperature range. This work has produced the additional result that the transition temperature, as evidenced by these anomalies, is sensitive to the stress in the specimen. This observation has led to certain arguments which seem to explain the anomalies and to relate them to the changes in the electron spin distribution.

Young's modulus and the shear modulus were determined for a number of pure polycrystalline chromium specimens by determining their resonant frequencies in both longitudinal and torsional vibration, and the variations in these properties were determined as a function of temperature. Then the same specimens were instrumented with resistance strain gauges, and the variation of

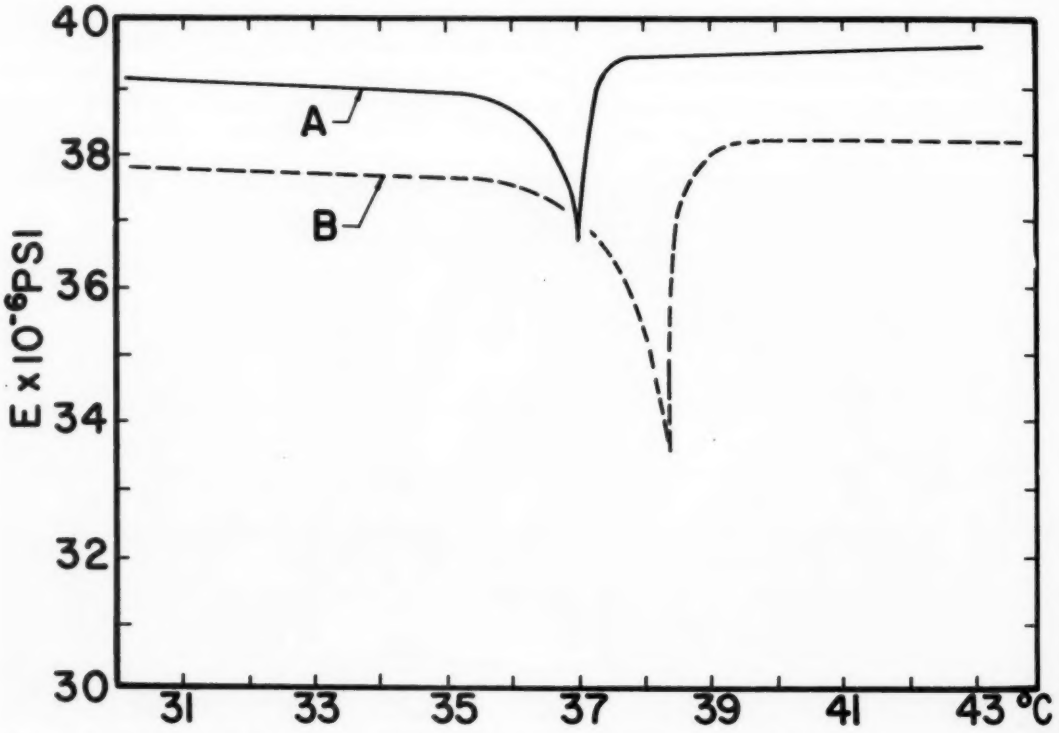


Figure 1 Variation in Young's modulus as a function of temperature and state of stress. Specimen No. 3. Curve A, values derived from sonic vibration. Curve B, values taken from load-strain curves.

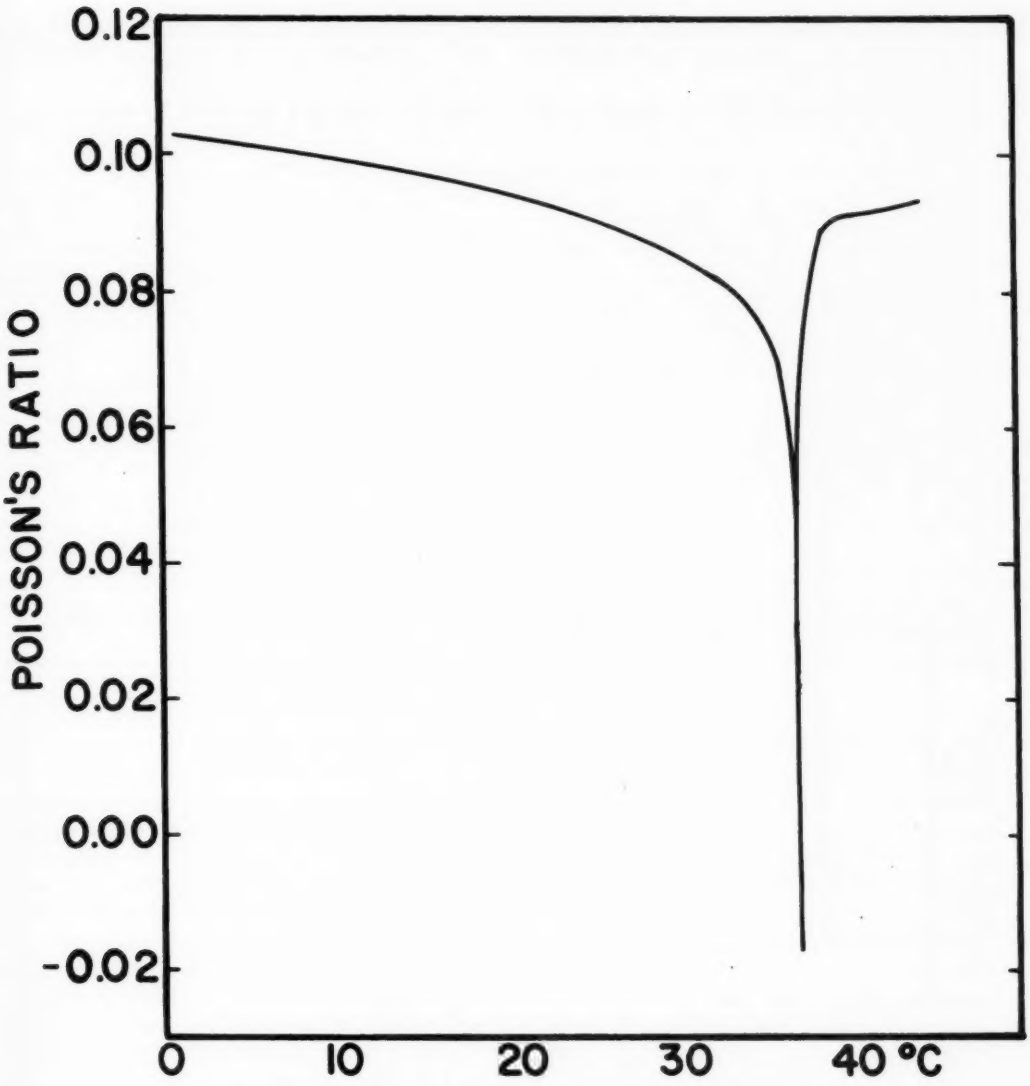


Figure 2 Poisson's ratio as a function of temperature, Specimen No. 1A.

Young's modulus and Poisson's ratio as a function of temperature was determined mechanically. The resonant frequency of a bar is determined by its elastic constants and its geometry. If its size and density are known, then its elastic constants can be computed from its resonant frequency.

Typical variations in Young's modulus and Poisson's ratio are shown in Figures 1 and 2. Note that Poisson's ratio is very nearly zero or slightly negative at 37° C as determined by our resonance measurements. The shear modulus was found to be comparatively insensitive to changes in temperature and to rise slightly over the temperature range studied. Our mechanical tests showed that applied tension raised the temperature of the anomaly (see Figure 1), while compression lowered this temperature with respect to the sonically derived value. This result was verified by a series of tests in which every condition was identical except the di-

rection of loading (see Figure 3).

The application of a uniaxial stress causes the transition temperature to shift because the stability of spin ordering depends on interatomic spacing. It is believed that this spacing in chromium is such that there is some overlap of the 3d orbitals when no stress is applied. A model has been proposed which shows that the stability of spin ordering is an inverse function of orbital overlap. Hence a compressive stress causes the transition temperature to decrease, and a tensile stress causes the transition temperature to increase.

The anomaly in Poisson's ratio is merely another illustration that all systems in equilibrium tend toward a minimum energy. If the chromium lattice is distorted below the transition temperature, the antiferromagnetic array is also distorted. However, the energy required to distort this array is greater than that required to distort the metallic lattice. As a consequence, the lattice will deform spontaneously in orthogonal directions to maintain symmetry of the magnetic array when a stress is applied to the metal. Since only two of the three elastic constants (E, G, and ν) can be independent, and since G is not sensitive to temperature, the anomaly in Young's modulus is a necessary consequence of the anomaly in Poisson's ratio. (For further information, see Journal of Applied Physics, September 1965, or consult the authors.) ★

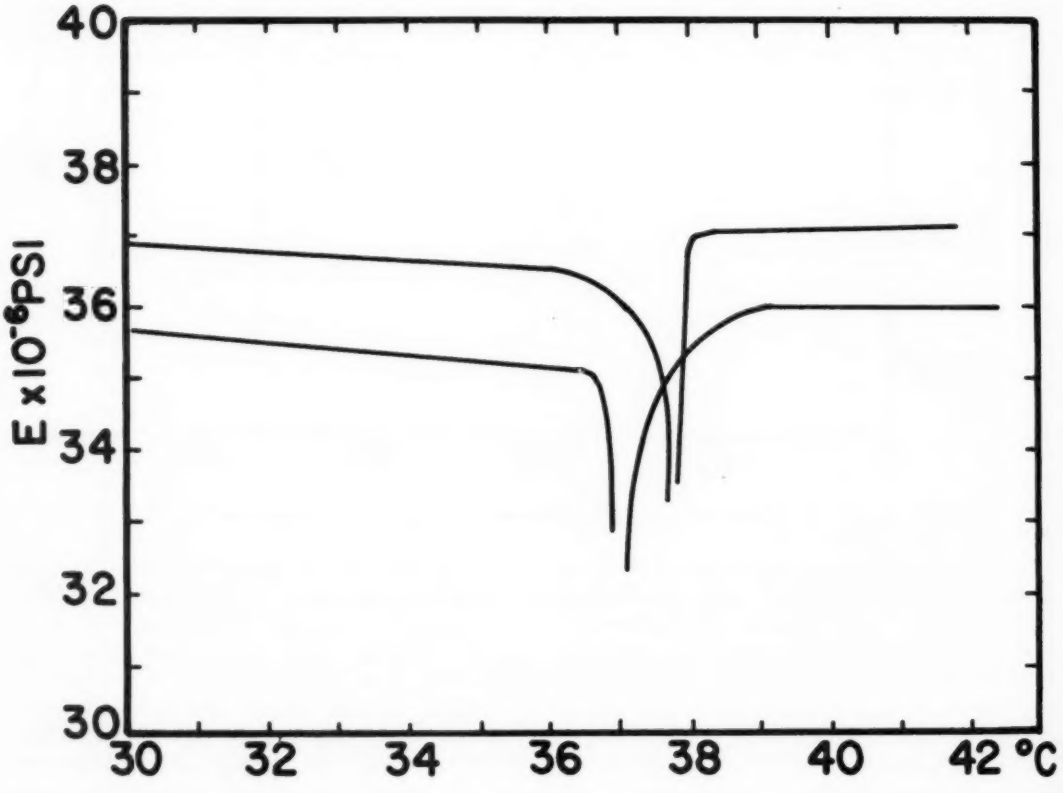


Figure 3 Young's modulus of specimen No. 2A as a function of temperature and state of stress. Values measured in tension, upper curve, and in compression, lower curve.

MOLECULAR MARKSMANSHIP (Molecular-Beam Research)

OPTICAL PHYSICS LABORATORY, AFCRL

If physicists and chemists were asked to predict research areas with high growth potential, most would place molecular-beam research high on their lists. Two recent AFCRL developments promise to accelerate this growth. These developments are two molecular-beam generators, the basic tools for molecular-beam research.

The two generators provide the scientist working in the field of low-energy physics with powerful new instruments for investigating processes hitherto impossible to observe with precision. Molecular-beam generators are to the low-energy physicist what the cyclotron or synchrotron is to the high-energy physicist. Molecular beams can be used to study atomic and molecular interactions in a manner analogous to the more familiar way in which streams of high-energy particles are used to study nuclear and subnuclear interactions.

Both molecular-beam generators under development at AFCRL are distinguished by the fact that they operate in the critical energy range between 1 and 10 electron volts, and that they deliver high-intensity beams. The familiar chemical processes that give the earth and its myriad components their dynamic variability occur largely in the 1-10 electron volt region. The microscale collisions of particles at these energies give rise to the macroscale physical and chemical reactions, regenerative mechanisms, and transformations of which life itself is one small part.

The first of these generators is being built entirely within AFCRL under the direction of Dr. A. T. Stair, Dr. Farid Hushfar, and Lt. James Rogers. This molecular-beam device, originally conceived by Dr. Hushfar, makes use of the charge-exchange principle. A stream of ions is accelerated by an electric field, then passed through a neutral gas where some of the ions acquire electrons from the neutral gas molecules. This device generates a continuous molecular beam with an intensity of 10^{12} molecules per square centimeter per second. Beam energies can be precisely controlled.

A second approach to the generation of high-intensity molecular beams is under development by an AFCRL contractor, American Science and Engineering. This approach, called the Mechanically Accelerated Sabot System (MASS), gives pulsed beams in the 1-10 ev range with beam intensities of 10^{22} molecules. This method is one in which a bullet is fired from a fixed rifle barrel. On leaving the barrel, the bullet is literally split apart, with the two parts deflected to either side. The gas, which is a high-intensity molecular beam, continues on to the target.

Both the charge-exchange and MASS molecular-beam generators will be used in a broad-based program of molecular-beam research directed by Dr. Stair. Dr. Stair initiated this research program in response to a growing practical need for more basic knowledge about what happens during molecular interactions.

Molecular beams, as such, have been used in research since 1911. A molecular beam is nothing more than a stream of molecules or atoms--an accelerated neutral gas. Such a stream is easy to generate. It is necessary only to place a material in an oven to increase molecular velocities. The heated particles escape through a small hole into an evacuated region. A stream of these molecules is created by using collimating slits. Molecular-beam devices based on such thermal energy principles have one basic limitation--energies seldom exceed 1/2 ev. Previous molecular-beam devices based on the charge-transfer principle also had serious limitations. The energies generated were much too high for use in most studies of interest, or else the beam intensity was too low. When the latter occurs,

the detectors must cope with a poor signal-to-noise ratio, and this means, in effect, low resolution.

The significance of the two AFCRL molecular-beam generators, then, is that they produce a high-intensity beam in the region between 1 and 10 ev, where there was previously a gap, and where most processes of interest occur. The charge-exchange molecular-beam generator developed by AFCRL is currently being tested.

One investigation to which AFCRL will apply its molecular-beam generators is that of gas-gas collisions and interactions. From these studies, Dr. Stair and his group hope to obtain a better understanding of the attractive and repulsive mechanisms at play when a particle of a particular velocity and mass, and of a given quantum state, approaches or collides with another. The reason that these mechanisms have not been clearly observed before is that, under normal conditions, reactions involve too many particles of differing states and velocities. Molecular-beam research permits the researcher to isolate selected parameters for observation.

Molecular beams in the 1-10 ev range should also become a valuable engineering tool, particularly in the area of hypersonic flight dynamics. At present, huge, expensive wind tunnels are required to study the effects of hypersonic gas flow on various surfaces, and the reaction rate of oxygen with various fuels in such a flow. The use of molecular beams will make it possible for the first time to determine basic hypersonic flow characteristics much more precisely and inexpensively. Such studies may lead to more accurate determinations of the performance of hypersonic aircraft, calculations of the decay of satellite orbits, and methods of discriminating decoys from missile warheads.

These problems in gas-surface interactions are related to the attractive and repulsive forces between a gas particle and the particles making up the surface of the material of the vehicle. The gas particles have largely unexplored trajectories around the surface, and the lattice structure of the surface itself is distorted in a characteristic way (producing a distinctive scattering pattern) by particular gas molecules. Drag coefficients can be calculated with precision only when it is possible to observe these microscale phenomena, which molecular-beam research permits. ★

DYNAMIC REFLECTANCE SPECTROSCOPY

DENTON W. ELLIOTT
Directorate of Chemical Sciences, AFOSR

Diffuse reflectance spectroscopy, at room temperature, is an important tool in structural studies on solid coordination compounds; but little work has been done with this tool at high temperatures. Dr. Wendlandt at Texas Technological College, Lubbock, Texas, under a grant from the Directorate of Chemical Sciences, AFOSR, has designed a temperature sample-holder for the spectrometer which will permit the reflectance spectra of a solid sample to be determined from ambient temperature to 500°C. In this technique essentially static temperatures were used; the temperature of the sample was held constant while the reflectance spectrum was scanned from 350 μ to 750 μ. By setting the spectrometer on a wave length at which a peak in the reflectance spectrum either increases or decreases with change in temperature, and the reflectance of the sample is measured as a function of increasing temperature of the sample, the technique becomes a "dynamic" one. The term, "dynamic," refers to the change in reflectance of the sample with a change in temperature. Because of the "dynamic" nature of this measurement, Dr. Wendlandt has called this technique "dynamic reflectance spectroscopy (DRS)."

Figure 1 shows the reflectance curves of $CoBr_2 \cdot 6H_2O$ in alumina. The curves derived from the new technique are shown in Figure 2.

The dynamic reflectance curves show the formation and decomposition temperatures for the intermediate hydrates and the anhydrous $CoBr_2$.

The technique of dynamic reflectance spectroscopy (DRS) appears to have promise,

in conjunction with other thermal methods, in the study of the thermal dissociation of colored compounds. It may also be applied to the study of solid-state reactions at elevated temperatures in which there is a colored reactant or product, and in kinetic studies of the formation and decomposition of colored compounds. Unlike other thermal methods, DRS may be used to monitor only a single reaction at a time, thus eliminating the effect of reactions occurring simultaneously. ★

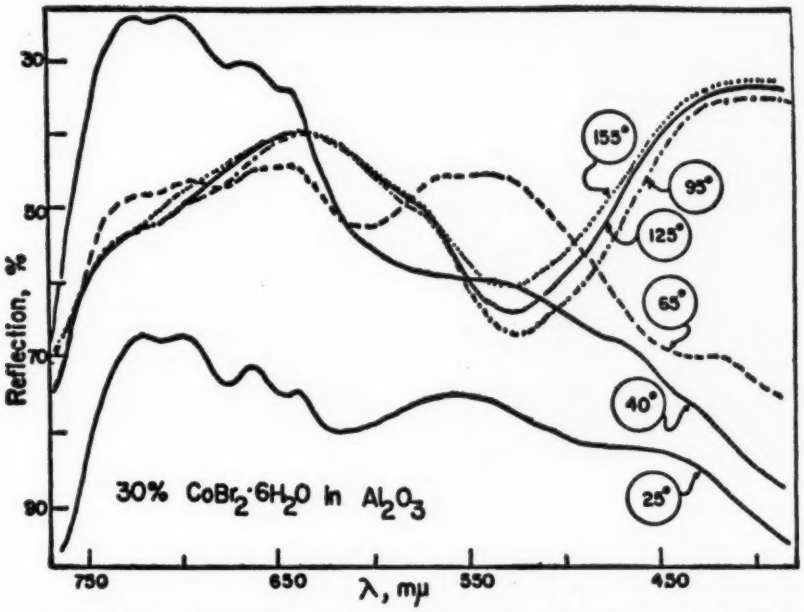


Fig. 1. Diffuse reflectance curves of a mixture of $CoBr_2 \cdot 6H_2O$ and Al_2O_3 at elevated temperatures. Reference material is Al_2O_3. Surface temperatures are given.

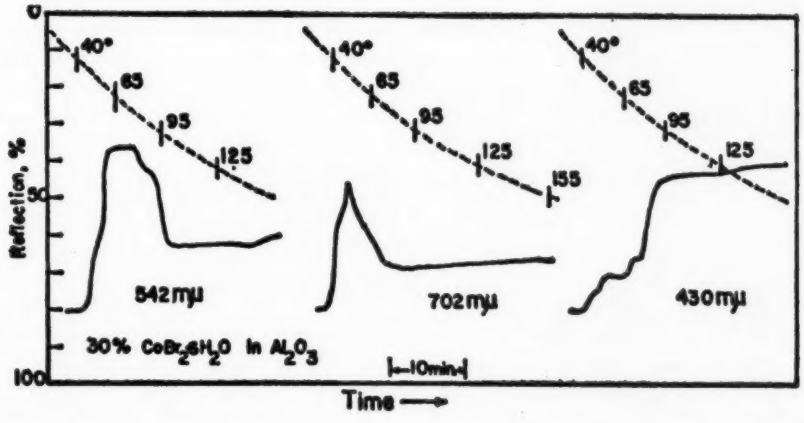


Fig. 2. Dynamic reflectance curves of a mixture of $CoBr_2 \cdot 6H_2O$ and Al_2O_3, 30 and 70 per cent, respectively. Surface temperature of the sample is indicated by the dashed lines.

PROFILES

Captain James E. Funk is a research associate at the Aerospace Mechanics Division, Frank J. Seiler Research Laboratory, USAF Academy. He is currently investigating computer applications of control optimization methods and techniques. He has a B.S. in Aeronautical Engineering and General Business from the University of Colorado, and an M.S. in Astronautics from the Air Force Institute of Technology. In this issue of the Review, Captain Funk writes on "SADSAC (Seiler Algol Digitally Simulated Analog Computer)."

Dr. Paruchuri R. Krishnaiah, mathematical statistician with the Applied Mathematics Research Laboratory, ARL, is currently concerned with four interrelated efforts in Multivariate Analysis. The first effort is to propose various methods and investigate the associated distribution problems for testing the hypothesis of equality of covariance matrices against several alternative hypotheses. The second effort is to investigate the applications of these tests in multivariate ranking and selection procedures. The third effort is to investigate the relative merits of the various multiple comparison tests in the multivariate case. The fourth effort is to construct a series of tables which will be useful in the application of multiple comparison tests in the multivariate case. Dr. Krishnaiah received a B. Sc. (Hons) in Statistics (1954) from Madras University, India, and an M.A. in Statistics (1957), and a Ph.D. in Statistics (1963), both from the University of Minnesota. He has a great number of publications to his credit. In this issue of the Review, he reports on the "International Symposium on Multivariate Analysis."

Mr. J. A. Roberson of the Metallurgy and Ceramics Research Laboratory, ARL, is coauthor of the article, "The Elastic Behavior of Chromium Depends on How You Test It--or Poisson's Ratio - The Variable Constant," which appears in this issue of the OAR Research Review. His current study of the mechanism of the fatigue limit in metals is centered around the close-packed-hexagonal metal, titanium, and alloys of Ti with interstitial elements. He is also investigating the fatigue behavior of pure molybdenum to determine the effects of environment on the fatigue behavior of this metal. Mr. Roberson received his B.S. (Met. E.) from Purdue University in 1956, and has participated in the graduate program of OSU extension from 1961 to the present. He has a number of publications to his credit, and has made several presentations at AIME Annual Meetings concerning his research efforts.

Dr. Denny D. Watson of the General Physics Research Laboratory, ARL, is author of "Some Nuclear-Structure Studies Using Gamma-Ray Angular Correlations" which appears in this issue of the OAR Research Review. He is currently concerned with properties of excited states of Cl^{35}, new and improved methods for the analysis of gamma-ray angular correlation data, and the design of mechanical and electronic systems to provide for gamma-ray polarization measurements. Dr. Watson received his B.S. (Engineering Physics) in 1960, and his Ph.D. (Physics) in 1965, both from the University of Kansas. Prior to joining ARL, he was a research assistant, Nuclear Physics Laboratory, University of Kansas, from 1958 to 1964.

SOME NUCLEAR-STRUCTURE STUDIES USING GAMMA-RAY ANGULAR CORRELATIONS

DR. DENNY D. WATSON, General Physics Research Laboratory, ARL

Much research has recently been devoted to the experimental measurement and theoretical description of properties of the so-called s-d subshell nuclei. This subshell includes nuclei with atomic mass numbers between 16 and 40. The properties of current interest are the energies of the excited states, their spins and parities, and transition probabilities for various modes of excitation or de-excitation from one nuclear-energy level to another.

Of particular interest to us have been the spins and parities of excited states and the electromagnetic transitions resulting in gamma-ray emission from the de-excitation of excited states. Spins and relative transition probabilities can be derived from measurements of the intensity-direction correlations of gamma rays from excited states formed by bombarding target nuclei by charged particles from an electrostatic accelerator. Measurements of the linear polarization of the emitted gamma rays can be used to determine the parities of the states.

The gamma radiations involved in such transitions are classified by multipole orders L, according to the angular momentum (in units of $\hbar$) carried off by each quantum. For each multipole order, there are two types of radiation, electric and magnetic, which differ with respect to parity. Electric dipole or E1, magnetic quadrupole or M2, electric octupole or E3, etc., connect states of different parity and carry 1, 2, 3, etc. units of angular momentum. The transitions denoted by M1, E2, M3, connect states of the same parity. If states of spin J_1 and J_2 are connected by a gamma radiation of multipolarity L, then the angular momentum quantum numbers $J_1 L J_2$ must add according to the rules of quantum mechanics so that $|J_1 - J_2| \leq L \leq J_1 + J_2$. The states J_1 and J_2 may, therefore, in some cases, be connected by more than one value of L. The transitions are parity conserving so that, for example, only mixings of the type E1/M2 may occur, but not E1/E2.

From the basic quantum theory of multipole radiations, it is possible to calculate the intensity-direction correlation of gamma rays of specified multipolarities cascading through levels of specified spin and starting from a specific magnetic substate of the initial nuclear excited level. The actual correlation function will then be a coherent sum of contributions from different possible gamma-ray multipolarities and an incoherent sum over the magnetic substates which may be occupied. The relative substate populations and multipole mixings cannot be predicted without recourse to a nuclear model and are, therefore, left as parameters. The correlation function may thus be calculated as a function of multipolarity mixings, substate populations of the initial state, and spins. Comparison of these theoretical correlations with experimentally measured correlations can, in principle, provide the correct values for the spin, mixing, and population parameters.

The importance of this type of measurement lies in the fact that the results are independent of any nuclear model and, therefore, provide information which is necessary to ascertain the validity of theoretical descriptions of the nuclear system. The major obstacle to these measurements has been the numerical complexity of determining the correct set of parameters with which to fit the experimental data. Numerical techniques have frequently been inadequate to solve the problem without imposing severe restrictions

on the range of parameters to be considered. Several members of the Nuclear Structure Group of ARL have recently been involved in modifying the formal description of angular correlations and developing numerical techniques and computer programs to facilitate the analysis of angular correlation data.(1) As a result, computer programs are now developed which can efficiently compare experimental correlations with the theoretical correlations for all physically possible values of spins, mixing and population parameters. The proper set of parameters is then determined by statistical analysis. If the data are insufficient to determine a unique set of parameters, the analysis will provide the range of parameters which can produce adequate statistical agreement with the existing experimental data.

The merit of this new system of data analysis is illustrated by the results of some recent work on the $S^{34}(p, \gamma)Cl^{35}$ reaction at the resonance formed at a proton bombardment energy of 1.214 Mev. This resonance leads to a state at 7.54 Mev which decays via the 3.16 Mev level to the ground state of Cl^{35}. Angular distributions and triple correlation measurements on the 7.54 → 3.16→0 cascade lead to a spin assignment of 5/2→5/2→3/2 when only dipole and quadrupole transitions are considered. The more general analysis discussed above has indicated that the spin sequence 7/2→7/2→3/2 would also agree with the original experimental data, provided some octupole mixing were allowed in the 3.16→0 transition. The theoretical correlation functions for the two alternative spin assignments are very similar but not precisely identical, and a study indicated that a specially designed angular correlation measurement, coupled with accurate data analysis, would distinguish between the two choices. The experiment has been performed, and the results indicate that the correct spin sequence is 7/2 →7/2→ 3/2. The analysis indicates that this conclusion is valid with a statistical certainty of 10^4 to 1. Polarization measurements result in negative parity assignments for both spin 7/2 levels.

These results have been interesting from several standpoints. The 3.16→0 transition is a mixed M2/E3 transition. The amount of mixing indicates an enhancement of the E3 transition strength over estimates based on a single particle model of the nucleus. Until very recently, E3 transitions had not been observed at all in the light nuclei. By now, however, enhanced E3 transitions have been observed in P^{31}, Si^{28}, N^{14}, and F^{19}, in addition to Cl^{35}. This may suggest that E3 enhancement is common in such nuclei, but has only recently been recognized in the light of more accurate data analysis. The spin and parity of the 3.16 Mev level indicate that this level must either have one of its outer nucleons elevated to the $f_{7/2}$ subshell, or have many nucleons involved in a collective octupole vibration. This makes the 3.16 Mev level unique among the low-lying levels which are expected to be positive parity s-d subshell configurations. Finally, this is the second pair of negative parity spin 7/2 states to be observed among nuclei in this mass region. The other pair of $7/2^-$ levels was discovered by Harris (2) in his work on P^{31} in this Laboratory. The experiments performed by Harris at the 2.187-Mev resonance in the $Si^{30}(p, \gamma)P^{31}$ reaction revealed the existence of $7/2^-$ levels at 9.42 and 4.43 Mev excitation. The spins, parities, resonance strengths, level spacings, decay modes, and mixings obtained from these resonances which populate the $7/2^-$ levels in Cl^{35} and P^{31} are remarkably similar. One is led to suspect that the similarity is more than accidental, and may indicate the existence of such levels in several of the s-d subshell nuclei. Such occurrences are worthy of careful study. ★

References

(1) *Harris, G. I., H. J. Hennecke and D. D. Watson, Phys. Rev., 139, 1113, 1965.*

(2) *Harris, G. I., H. J. Hennecke and F. W. Prosser, Phys. Letters, 9, 323, 1964.*

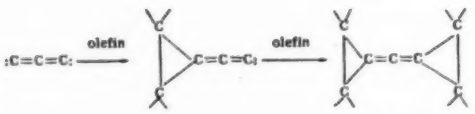
LABILE SPECIES OF CARBON

DR. ANTHONY J. MATUSZKO
Directorate of Chemical Sciences, AFOSR

Research supported by the Directorate of Chemical Sciences, AFOSR, has resulted in important discoveries which have contributed significantly to the general area of carbon chemistry. Detailed studies of the formation, reactivity and properties of active species of carbon were carried out at Pennsylvania State University under the direction of Dr. Philip Skell. Dr. Skell and his co-workers have devised methods of selectively producing monoatomic and triatomic carbon, C_1 and C_3, in the ground and excited states, and reacted these various forms of carbon with organic molecules such as olefins and alcohols.

The C_3 form of elemental carbon was discovered by spectroscopic methods in the atmosphere of comets over 20 years ago. In the past few years, optical and mass spectroscopic analyses of carbon vapors resulted in the detection of carbon species ranging from C_1 to C_5. However, until the recent work by Dr. Skell and his co-workers, little was known of the chemical properties of these substances.

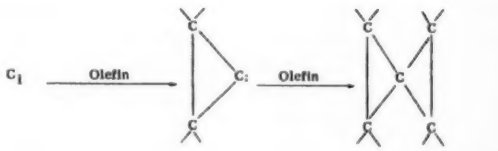
First studied were the reactions of C_3 with olefins, in which case homologs of bis-ethanoallene were formed: (1)



a bis-ethanoallene

The addition of ground (singlet) state C_3 was stereospecific, and cis and trans 2-butene produced different isomeric allenes. The excited (metastable triplet) state C_3 did not add stereospecifically. Details of the findings with Dr. Skell's interpretations may be found in a paper published in the Journal of the American Chemical Society. (2)

Following the very interesting discoveries pertaining to C_3, Dr. Skell's attention was directed towards learning more about the chemistry of the monoatomic carbon. Products of the triplet ground state of C_1 (^3P spectroscopic state) as well as two different excited singlet states (^1S and ^1D spectroscopic states) were selectively produced. The ground state addition to olefins is stereospecific in the first step and non-stereospecific in the second, producing a spiropentane; the ^1D excited state adds stereospecifically to the olefins in both steps: (3)



a spiropentane

The excited states of C_1 also yield other reaction products.

A diagram of the apparatus used by Dr. Skell and his co-workers for the production of C_1 and C_3 is shown in Figure 1.

The reaction flask shown was immersed in liquid nitrogen and connected to a high vacuum system (at least 10^{-4}mm of Hg). The general reaction procedure involved the generation of the active C_3 and C_1 by striking the arc and the simultaneous addition of the reactant olefin gas. The proportions of C_1 and C_3 were varied by changing the current. The ground states of both C_1 and

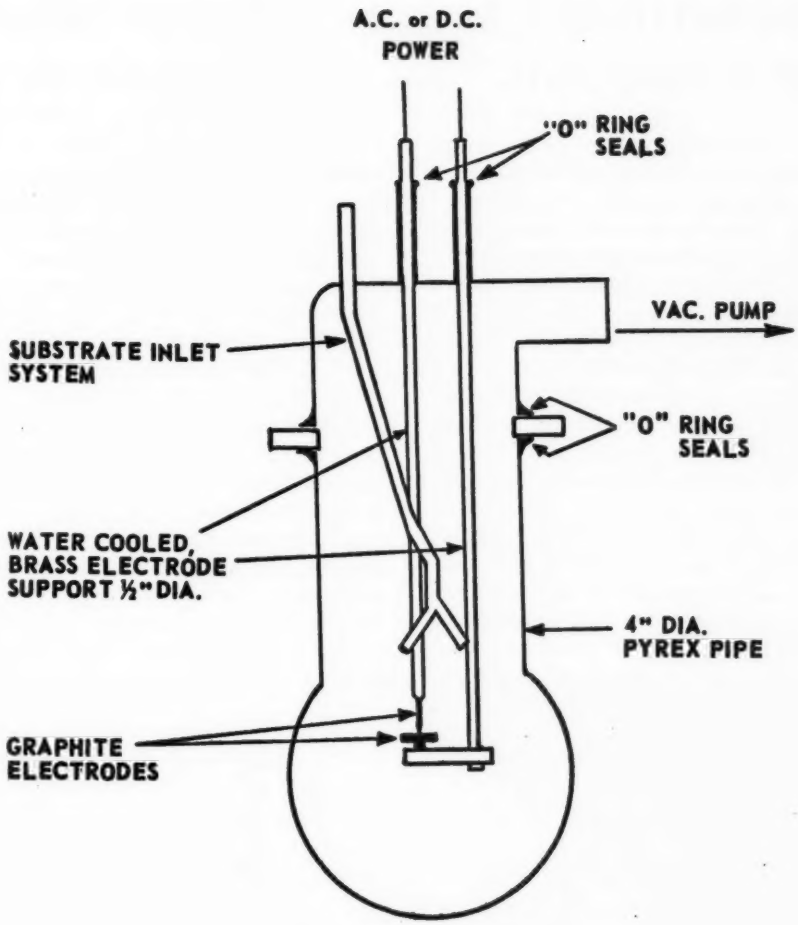


Fig. 1. Reaction Chamber

C_3 were found to be stable in a paraffin matrix at liquid-nitrogen temperature. Thus, it was possible to generate both species and store them on the walls of the reaction flask for several hours. (The walls may be coated with the trapping reagent prior to, simultaneously with, or after the deposition of the carbon vapor.) This makes possible direct observations of the physical properties of C_1 and C_3 prior to introduction of the olefin.

Dr. Skell hopes to be able to describe the properties of C_2 in the near future. Thus far it has appeared in much smaller quantities than either C_3 or C_1. In addition, he hopes to expand this program of research to include a wide range of high-temperature species: all the atomic species, stable gaseous metallic oxides, carbides, borides, etc. This information will be useful to the Air Force not only in the synthesis of novel organic and organometallic materials, but also in the understanding of the behavior of structural materials on exposure to high temperatures, particularly upon re-entry of space vehicles into the earth's atmosphere.

References

(1) J. Am. Chem. Soc., 85, 1923, 1963.
(2) J. Am. Chem. Soc., 87, 2829, 1965.
(3) J. Am. Chem. Soc., 87, 1135, 1136, 2493, 1965.

organizational behavior in a disaster stress situation

DR. H. J. SANDER, Directorate of Life Sciences
AFOSR

AFOSR gave initial support, and is participating in continued support, of a pioneering effort by behavioral scientists at Ohio State University who are studying the effects of stress on complex organizations in disaster and crisis situations.

Under the leadership of Professor Eugene Haas and his associates, Dr. Russell R. Dynes and Dr. E. L. Quarantelli, a Disaster Research Center was established in 1963. It is the only one of its kind in the world. Concerted efforts to study disaster are only about a decade old. The first major source of disaster research in this country was the Disaster Research Group (formerly the Committee on Disaster Studies) of the National Academy of Sciences, National Research Council. This group was disbanded in 1963. In order to continue this important area of research, the Disaster Research Center was established at Ohio State, in the same year, with initial support by the Behavioral Sciences Division of AFOSR and the Office of Civil Defense, Department of the Army.

Why study organizations under stress? It is generally recognized that the understanding of modern man and the society in which he lives is critically dependent on the study of complex organizations. One of the most important ways of learning to understand organizations of all types, including the military, is to study how they react to stress situations. Crises reveal, as few situations can, how organizations are structured, how

One of three Police Communication teams which participated in three "normal" sessions and one "stress" session in the Ohio State University Behavioral Science Laboratory. The "stress" session involved a simulated crash of a jet airliner into several apartment houses. This "event" resulted in a 300% increase in incoming calls requiring organizational action.

they change, and how they fulfill their functions.

In order to accomplish this task systematically, the Ohio State Disaster Research Center's program is conducted in three phases concurrently: field studies, intermediate investigations, and laboratory simulation experiments.

For the field studies, research teams have been assembled and remain ready to conduct emergency interviews of organization management people in a disaster area as soon after the event as they can get to the site. Persons interviewed are usually organizational heads or operational officers. Teams have been sent to such disaster sites as earthquakes in Alaska and Japan; dam breaks in Longarone, Italy, and Baldwin Hills, California; hurricanes and tornadoes in Texas and the Midwestern States.

The intermediate-phase investigations are crisis situations over which there is some control. For example, an Air Force base had a research team observe a run-through of a base alert when a plane with an atomic weapon supposedly was to make an emergency crash landing. Here the variables of a contrived situation were controlled and new ones introduced.

In the laboratory simulation studies, the researchers have contrived an instrumented laboratory setting in which an organizational response to a disaster situation can be reproduced so all factors can be under control. The purpose of such studies is to generate and test hypotheses about how certain organizations react to various levels of stress and crisis situations.

A recent study involved the communications group of a police department. This group was placed in a "police radio room" where the members were assigned tasks identical to those they performed daily. Various emergency irregularities and crisis situations were introduced into the controlled system by the experimenters, and the resulting responses were put on videotape. The principal investigator, Dr. Haas, reports that "the police group found the simulation to be quite realistic and became very involved in it. They reported that the stress was so real that they could think of nothing else for several hours." The central hypothesis of the framework was supported, i.e., if there is organizational stress, then there will be change in organizational performance structure. Among the more specific hypotheses supported were: (1) as the degree of organizational stress increases, the rate of task performance will increase; (2) as the degree of organizational stress increases, organizational incumbents will increasingly limit their activities to those tasks of highest priority; (3) as the degree of organizational stress increases, there will be an increase in the rate of decision-making; (4) as the degree of organizational stress increases, the total amount of communication will increase.

Professor Haas has been named to the Geography Panel in the Division of Earth Sciences established by President Johnson to provide a comprehensive scientific and technical account of the Alaskan earthquake and its effects. The panel is responsible for reporting on the impact of this earthquake disaster on human behavior. Findings will be part of a book to be published by the National Academy of Sciences. ★

curious cloud structure

METEOROLOGY LABORATORY, AFCRL

Three long, plume-like clouds, the longest being some 180 miles in length and 3 to 13 miles in width, showed up on a photograph taken by the Tiros VII weather satellite over the Pacific Ocean last year. The curious cloud picture was sent to AFCRL's Meteorology Laboratory by AFSC's Electronic Systems Division for interpretation.

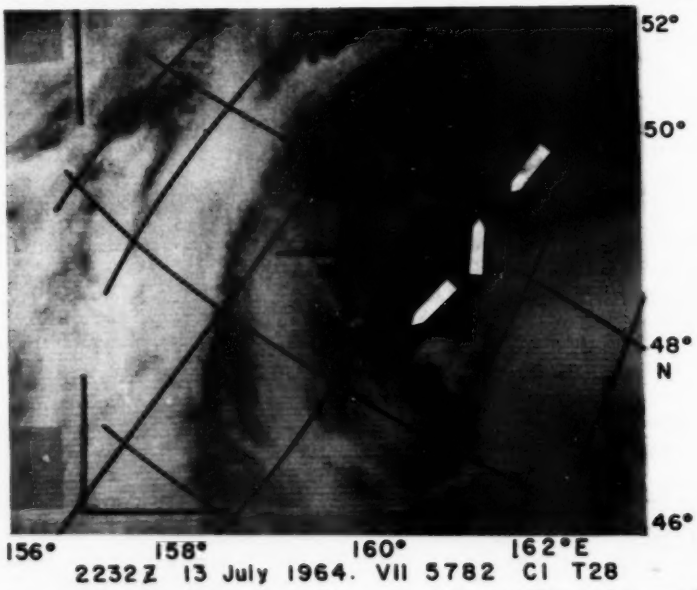
The long, narrow clouds were unlike any that had been observed before by weather satellites. On the photograph, the clouds appear as three roughly parallel lines similar to curved smoke plumes having narrow dense ends near their source. These lines were superimposed on a large low-level cloud system. John Conover of AFCRL, who analyzed the photo, determined that the three narrow lines were not part of the natural

cloud system, although their older portions appeared to be at the same level as the large cloud system.

After studying the photograph, Conover suggested that the cloud lines had risen slowly from a level near the ocean, (where they had been parallel to the wind), to the level of the natural clouds. At the upper level, they acquired the same small-scale pattern of the natural clouds and were distorted in unison as they crossed major bands of the large system. For these reasons, contrails, which are found at high levels, were ruled out as a possible source. His preliminary interpretation concluded that the most likely sources of the cloud lines were large quantities of moisture added to the atmosphere by stationary ships, such as whaling vessels or factory ships that process their catch at sea. A less likely possibility was that the lines represented smoke screens from naval vessels on maneuvers.

Subsequent to this analysis, a search for similar lines was made through all the Tiros photography taken over the North Pacific for a 1½-year period. This search turned up 13 additional cases, some of which appeared on adjacent days in the same area. All of these cases occurred in areas of high pressure characterized by low-level, inversion-dominated convective cloud systems. All the cloud lines occurred at temperatures that were above freezing. In some cases, lines crossed each other and, in one instance, a line 350 miles long was found.

Further inquiries ruled out smoke screens as a possible source, and analysis of some of the cases strongly suggests that moving, rather than stationary, vessels generate the clouds. Conover showed in one case that the wind component perpendicular to the ship's course increased along the course and that this could account for the curved crossing lines. Furthermore, using this idea, some of the lines appeared to be as much as 18 hours old. Estimates of water-vapor output from combustion products on board vessels have been obtained, and attempts to compute their diffusion will be made. If these deductions are correct, the effluents from ships, under rather special atmospheric conditions, have served to produce what appear to be the largest man-made clouds ever observed.



Curious Cloud Structure. The arrows in this Tiros photograph point to three long, narrow clouds which AFCRL scientists have determined to be man-made, most likely the result of whaling factory ships. These clouds may extend more than 200 miles in length.

TO OUR READERS

Request for further information should be directed to the individual or laboratory of origin (except for those from Latin America).

Addresses are as follows:

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
Attn: CRI
Laurence G. Hanscom Field, Bedford, Massachusetts 01731

AEROSPACE RESEARCH LABORATORIES
Attn: ARI
Wright–Patterson Air Force Base, Ohio 45433

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Attn: SRGL
4th and Independence Avenue, S.W., Washington, D. C. 20333

OFFICE OF RESEARCH ANALYSES
Attn: ORR
Holloman AF Base, New Mexico 88330

THE FRANK J. SEILER RESEARCH LABORATORY
USAF Academy, Colorado 80840

Request for further information from institutions and individuals in Latin America should be addressed to:

LATIN AMERICAN OFFICE AEROSPACE RESEARCH
U. S. EMBASSY
Rio de Janeiro, Brazil

Detailed documentary reports may be obtained from:

CLEARINGHOUSE
U. S. Department of Commerce, Springfield, Virginia 22151

DEFENSE DOCUMENTATION CENTER FOR SCIENTIFIC AND TECHNICAL INFORMATION*
Cameron Station, Alexandria, Virginia 22314

* Qualified requestors

GPO 898-830